WFIRST needs 3 microns

Ned Wright

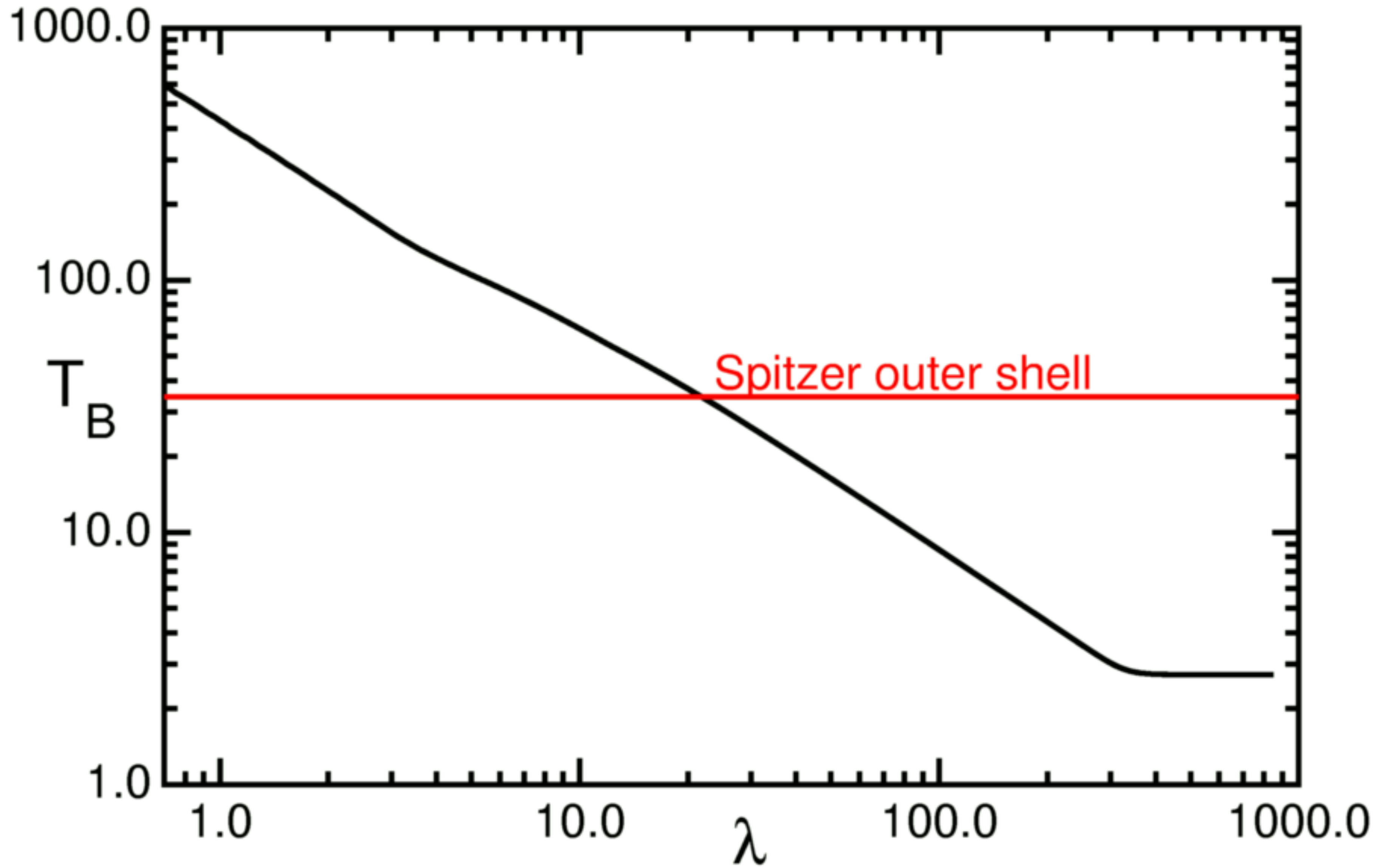
10 March 2011

Space is Cold

- COBE in LEO equilibrated at 55 K
  - InSb still worked great
- AKARI at T < 50 K in LEO with a cryocooler
- WISE in LEO equilibrated at 74 K
  - HgCdTe still worked great, even with 5.4 μm cutoff
- Spitzer in solar orbit equilibrated at 35 K

- Telescope will naturally be cold in space and cold testing will be necessary

Brightness T of Space Background



HST is heated

- Mirrors designed for 295 K, actually at 288 K
- Baffle tube has gradient but 253 K is typical
- IR power radiated by a 2.5 m diameter blackbody at 253 K is 1.1 kW
- Hubble solar arrays provide 2.8 kW in addition to attitude kicks and long settling times

∴ WFC3 IR channel does not operate beyond 1.8 microns – a problem for z=10 science

Mantra

- It is not

~~FLY as you TEST~~

- But rather

TEST as you FLY

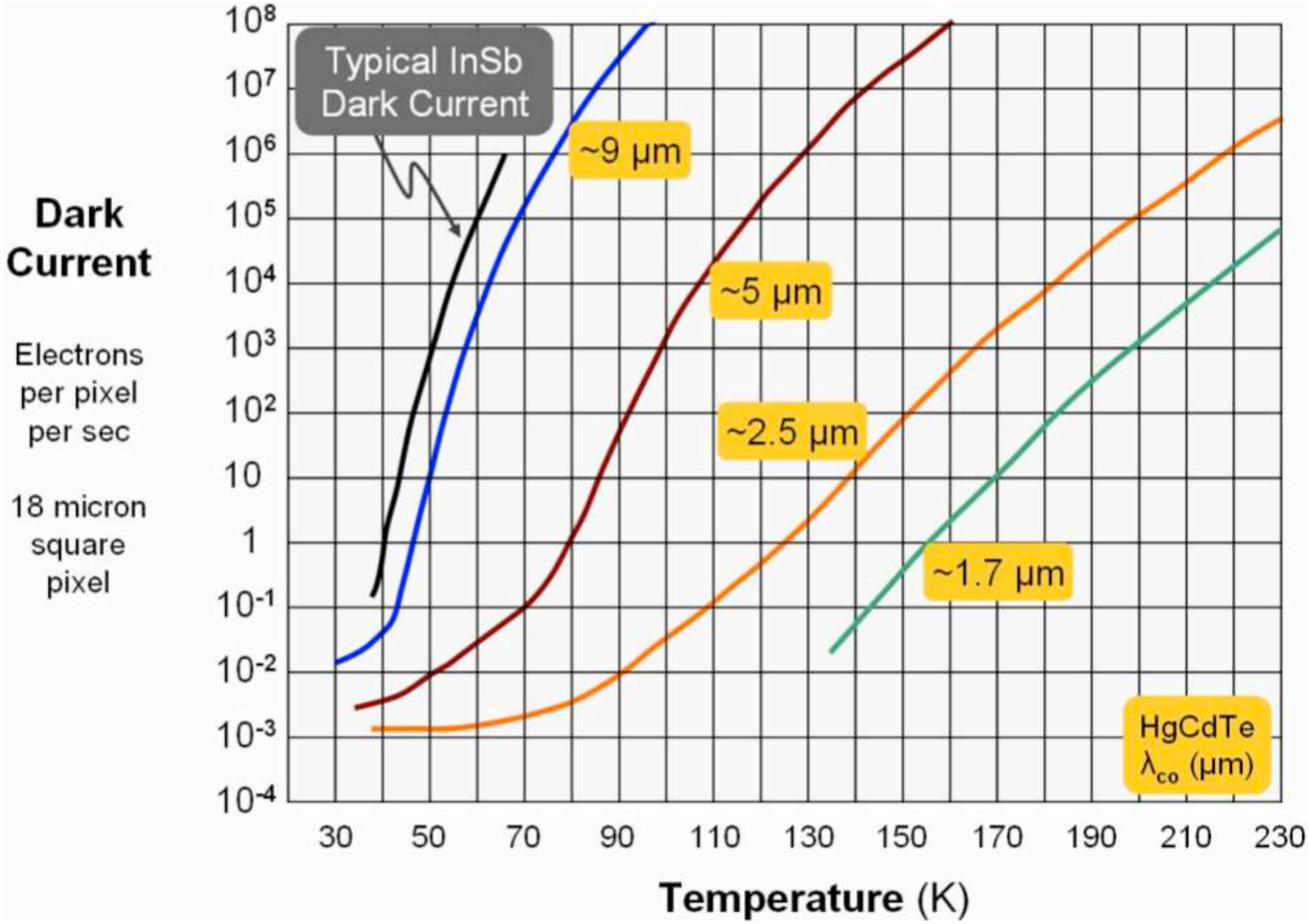
Testing Costs

- Room temperature is easiest
- But 100 K is not easier than 77 K
  - Probably harder
- Aluminum is an Ultra-Low Expansion material for T < 77 K

Detector Costs

- Almost all HgCdTe devices are sold as tracking devices for missiles
- These seek on the 3.3 μm PAH feature in engine exhaust gas
- 2 μm cutoff material is special, ~4 μm cutoff is standard

HgCdTe Dark Current vs T and λ_c

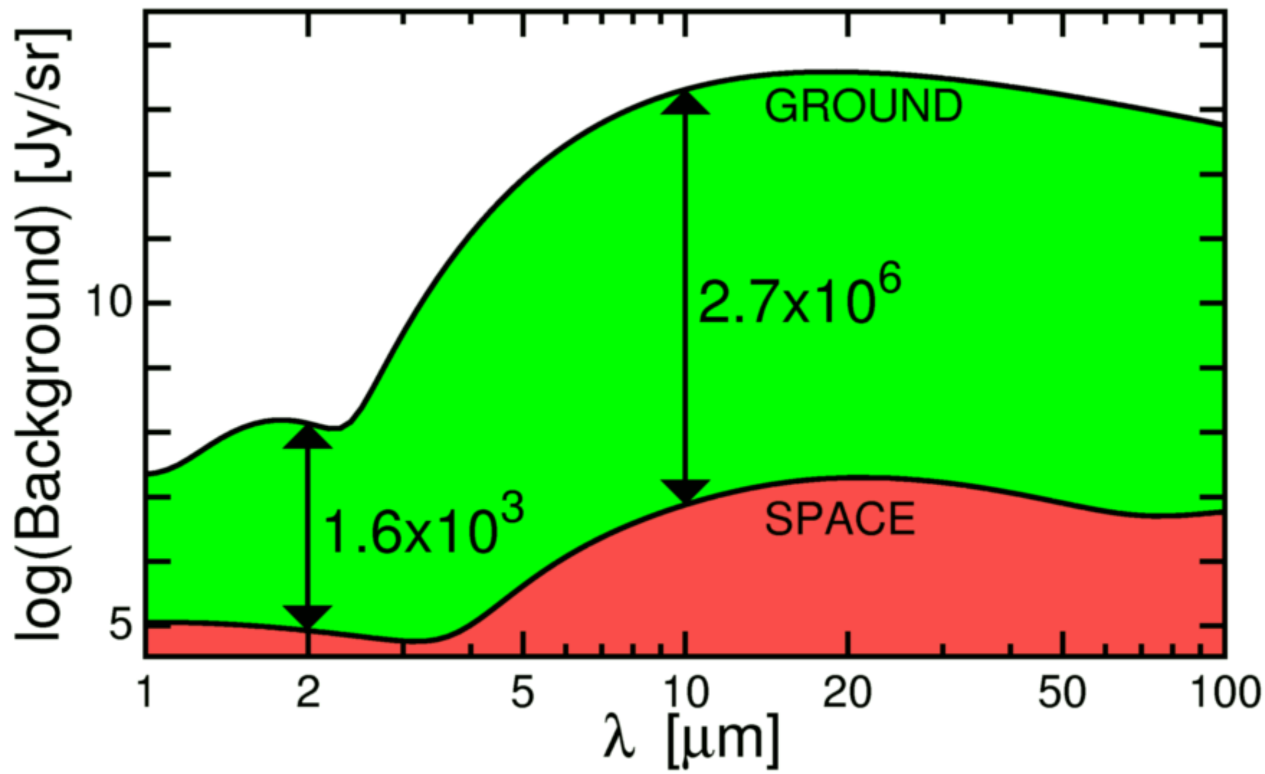


- From Beletic, 2008, ProcSPIE, v7021

- 1 e/sec like a 173 kJy/sr sky in JDEM-Ω

Space vs Ground

- Space hardware costs 1000x more than ground-based.
- WFIRST needs a huge advantage over ground-based instruments to beat out LSST.



- The 1600:1 background ratio was not enough to sell NIRAS in 1988
- 2.7 million to one ratio was sufficient to sell Spitzer and WISE

Synoptic All Sky IR: Mirror is Cast

- Will be ~10^3 times more sensitive than 2MASS over 30,000 square degrees in YJHK.

NIRAS in 1988

- NIRAS SMEX proposal in 1988. Fazio as PI. CJL & ELW as co-I's.
- "Big" Arrays: 58x62
- Constant inertial rate
- Scan mirror to freeze images on arrays
- All-sky survey at 1.9 and 3.5 μm
- Review panel suggested ground-based survey.
  - NIRAS was not funded!
  - But this suggestion led to 2MASS
- Bottom Line: near-IR only in space will not be an easy sell!
- Mid-IR like WISE is sellable.

PROPOSAL TO
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
FOR A
NEAR-INFRARED ASTRONOMY SATELLITE

P1976-9-88

For the period 1 July 1989 through 30 September 1993

Total Estimated Cost: $15,457,092
(not including costs from NASA Centers)

Volume I – Investigation and Technical Plan

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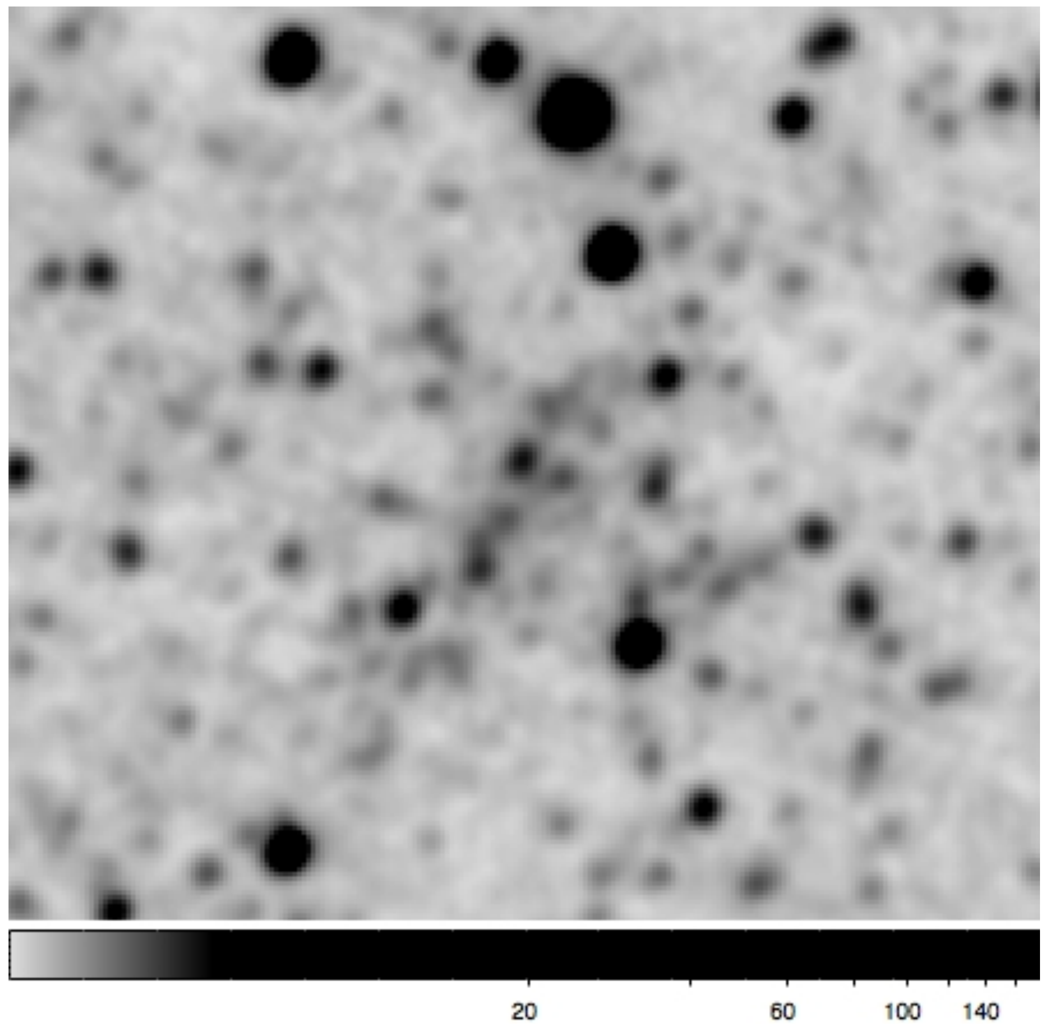
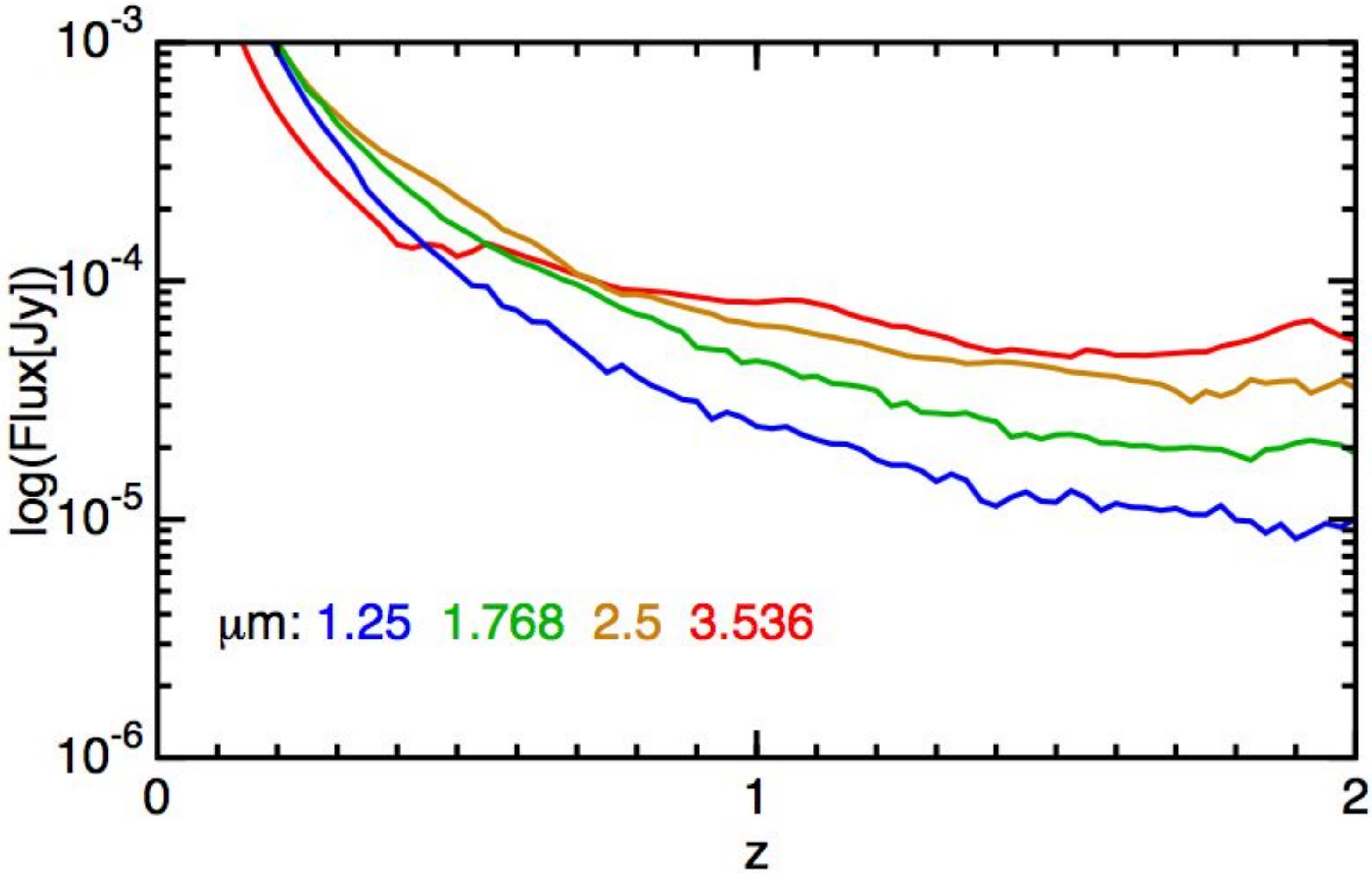
SPT galaxy cluster at z~1.2



- WISE band 1 image. WFIRST goes 1000x deeper

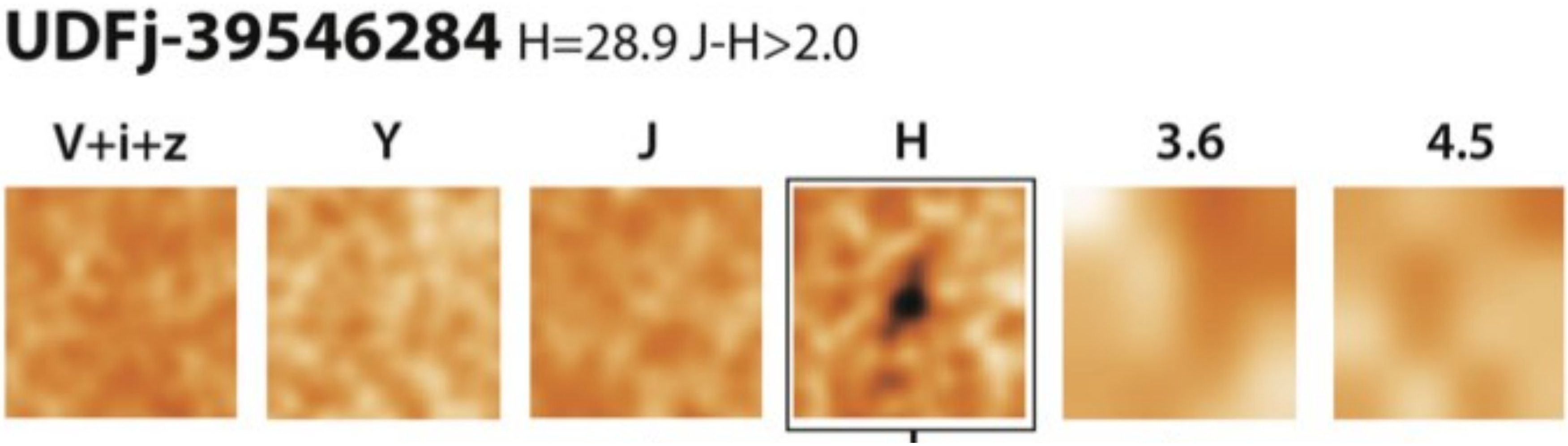
L* galaxy flux vs z



- from Adam Stanford based on Charlot&Bruzual 2007, z_f=3

- Galaxies are brighter at 3.5 μm, except at low z

Redshift 10 galaxy?



- Bouwens etal, 2011 (arXiv:0912.4263v5)

- Only an H band detection.
- Spitzer FWHM barely smaller than the boxes
- Really need K or L band data to measure the UV slope β and also improve the phot-z

PHoto-z Accuracy Testing

- Hildebrandt etal. arXiv:1008.0658

- “Half of the codes do not benefit from adding mid-IR photometry from the Spitzer Space Telescope. This finding suggest[s] strongly that there is considerable inaccuracy in some of the template sets in the rest-frame mid-IR region of the SEDs.”
- “The rather large outlier rates reported in this test should be taken seriously”
  - *"It's not so much what you don't know that can hurt you, it's what you think you know that ain't so."*
    - *Will Rogers*

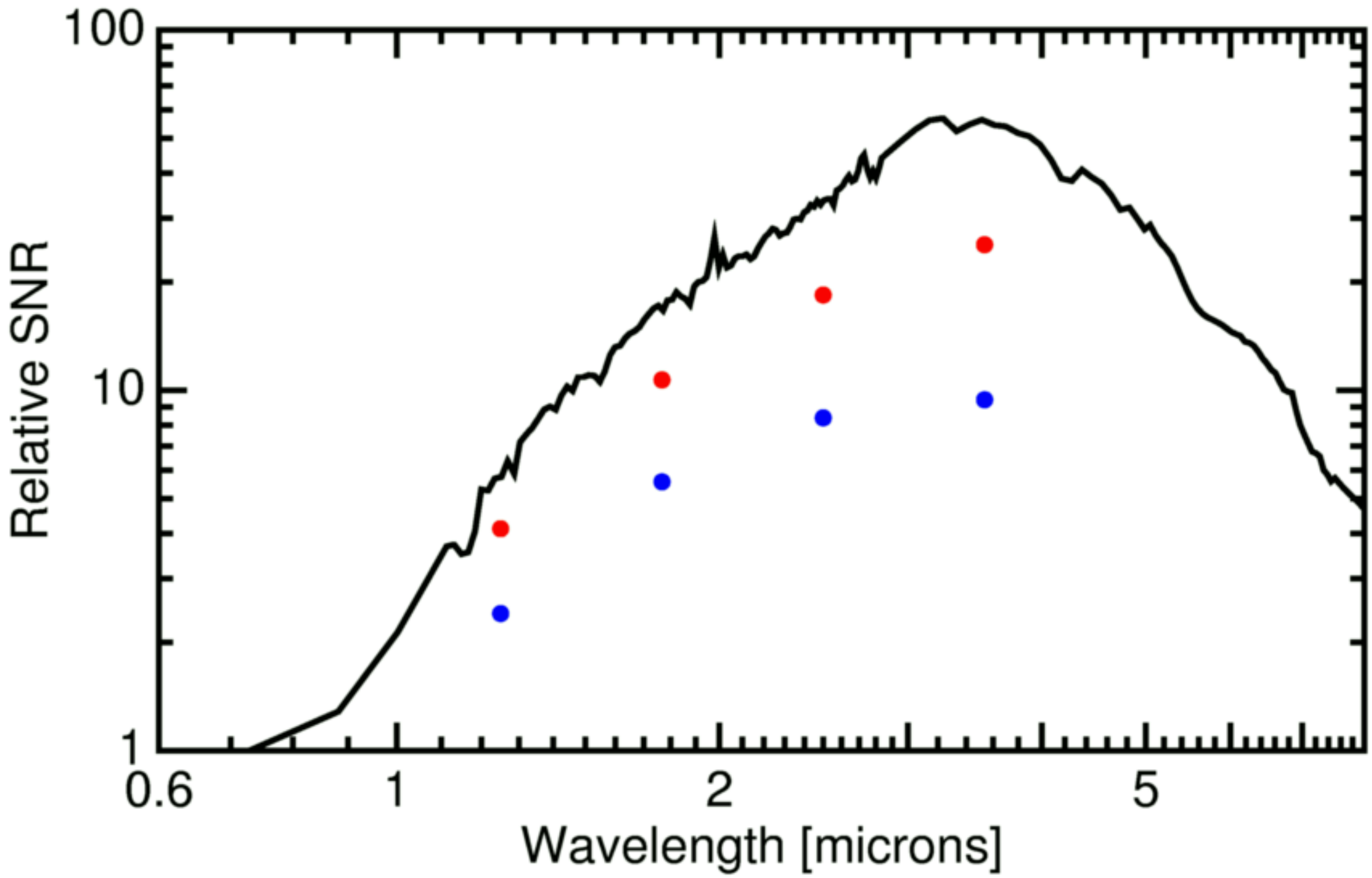
SNR Calculations

- Based on a spiral galaxy SED from Marcia Rieke redshifted to z=2. $[2.15-3.6]_{AB} = 0.84$
- A DIRBE-based zodiacal model from ELW.
- Assume an exponential disk scale length $\theta_e = 0.1''$
- Diameter D=1.6 m, 30% linear obscuration
- Pixel size 0.18”
- Diffraction-limited, background-limited.

Calculation Details

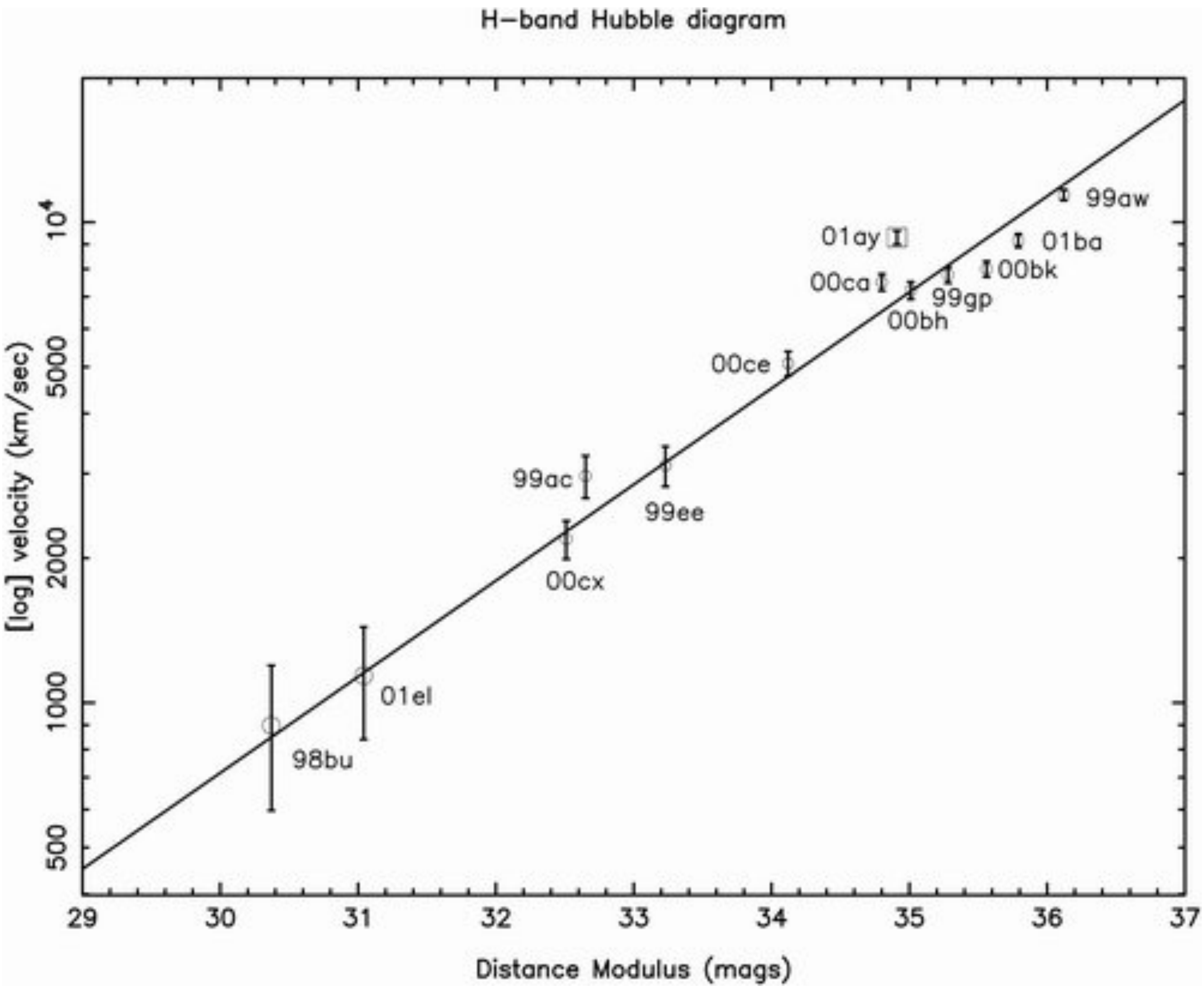
- Intensity signal $I(x,y) = \exp(-r/\theta_e)$
- Shear signal $S(x,y) = 5[I(1.1x,0.9y)-I(0.9x,1.1y)]$
- Tabulate on 0.02” grid spacing
- Use FFT to convolve with PSF of 1.6 meter diameter and 30% linear central obscuration, then block into 9x9 squares for 0.18” pixels, giving $\hat{I}$ and $\hat{S}$
- Compute noise pixels $N_p = (\Sigma \hat{I})^2/\Sigma (\hat{I}^2)$
- “Shear noise pixels” $N_s = (\Sigma \hat{I})^2/\Sigma (\hat{S}^2)$
- Relative SNR = $F_\nu/(N_p B_\nu)^{0.5}$
- Shear SNR = $F_\nu/(N_s B_\nu)^{0.5}$

SNR on z=2 spiral galaxy



- Black curve is for infinite resolution. Red points are for flux measurements, blue points are for shear measurements, both with $\theta_e D = 0.8\ \mu m$.

Carnegie Supernova Project



Rest frame H band is better for supernova Hubble diagram: smaller systematics.

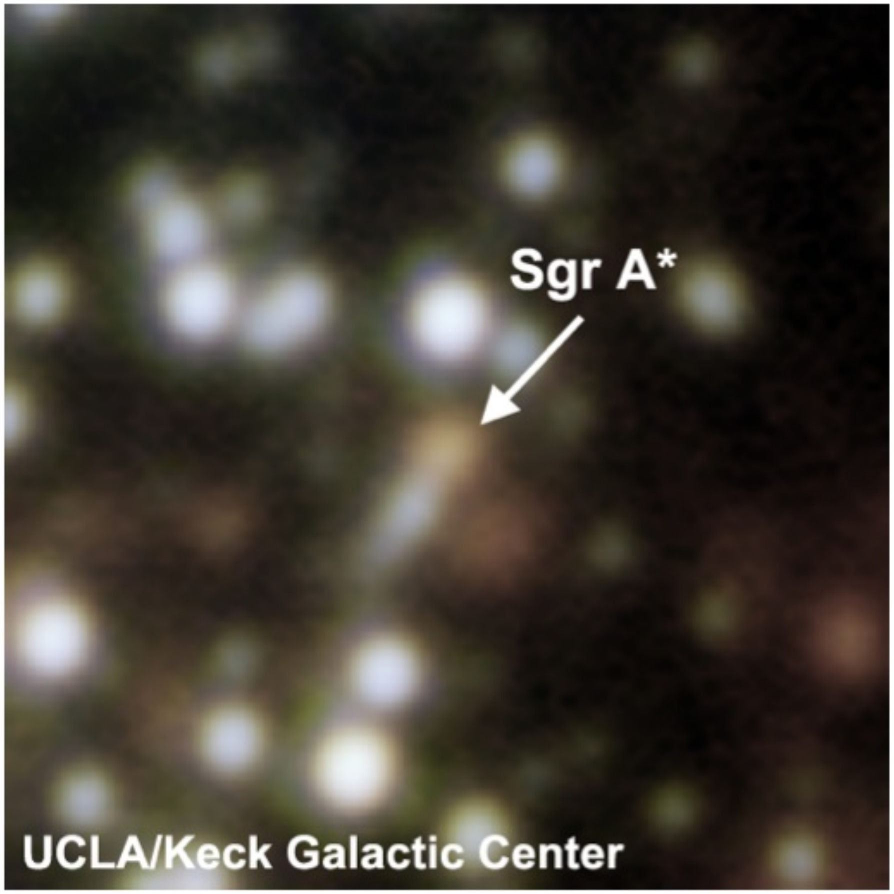
At z=1.5 this is 4 μm observed

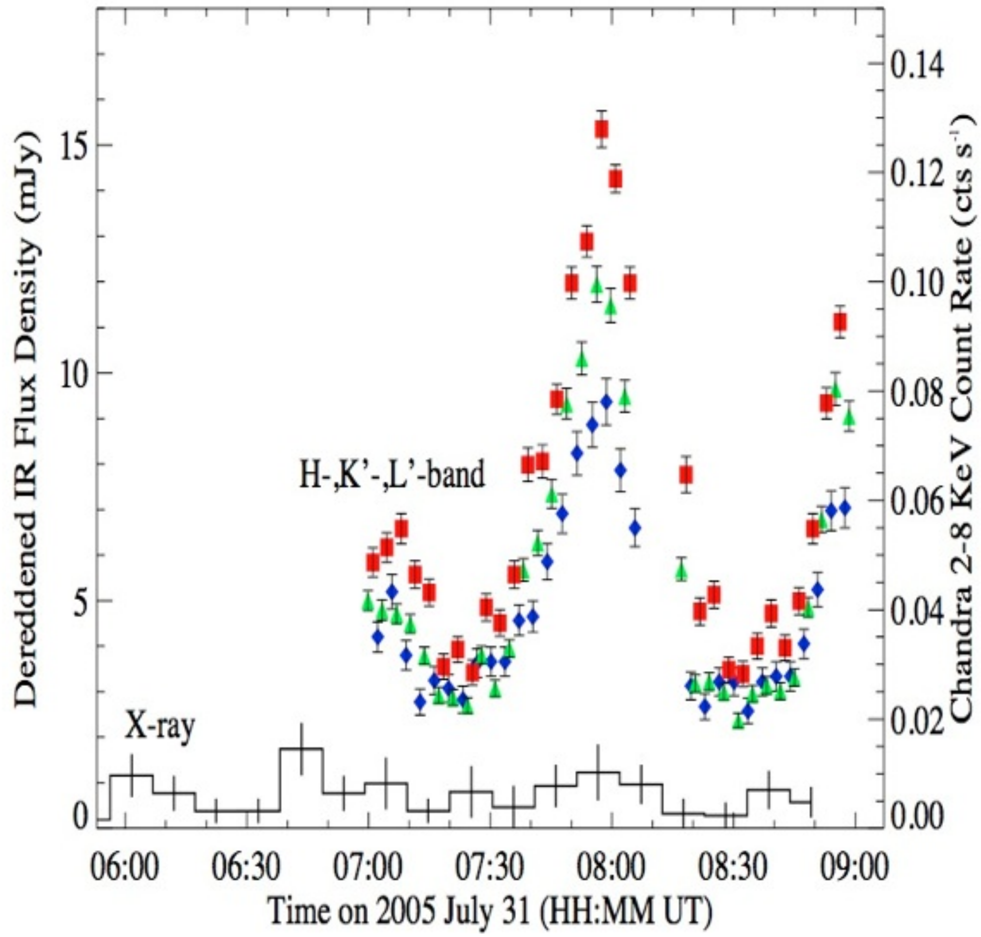
Krisciunas et al.

Eclipses of Hot Jupiters

- Currently big business for warm Spitzer
- Depth $(R_p/R^*)^2\ B_\nu(Tp)/B_\nu(T^*)$
  - For 1 Jupiter radius, 1 solar radius, Tp=1000 K
    - 0.00019 at 3.536 μm
    - 0.000020 at 2 μm
- So going to 3.5 microns is 10x better

Obscured AGNs





- Hornstein etal 2007, ApJ, 667, 900

- Extinction at 3.5 µm is 3x smaller than at 1.6 µm

Conclusions

- Don’t follow the 30+ year old Hubble design choices that were driven by the NRO
- Euclid, LSST, VISTA, SASIR and (Big)BOSS will hack away at the justification for a 1-2 μm WFIRST
- The JWST era needs a wide field infrared survey telescope that will work in the JWST band
- The zodiacal foreground defines a sweet spot at 3-4 μm. SNR is better even for shear if the telescope is big enough
- No additional testing costs, no additional detector costs for much greater versatility.